

# The Role of Congruency for Distractor-Response Binding: A Caveat

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## ABSTRACT

Responding in the presence of stimuli leads to an integration of stimulus features and response features into event files, which can later be retrieved to assist action control. This integration mechanism is not limited to target stimuli, but can also include distractors (distractor-response binding). A recurring research question is which factors determine whether or not distractors are integrated. One suggested candidate factor is target-distractor congruency: Distractor-response binding effects were reported to be stronger for congruent than for incongruent target-distractor pairs. Here, we discuss a general problem with including the factor of congruency in typical analyses used to study distractor-based binding effects. Integrating this factor leads to a confound that may explain any differences between distractor-response binding effects of congruent and incongruent distractors with a simple congruency effect. Simulation data confirmed this argument. We propose to interpret previous data cautiously and discuss potential avenues to circumvent this problem in the future.

## KEYWORDS

action control  
distractor-response binding  
congruency sequences  
sequence analysis

## INTRODUCTION

Successfully performing an action leaves a lasting trace in the cognitive system: Features that were used to represent, plan, and initiate the action are automatically integrated with features of the current situation, and the structures that include these bindings of stimulus- and response-features are often labeled *event files* (Frings et al., in press; Hommel, 1998, 2004).

An elegant way to study binding and retrieval of event files is the *distractor-response binding paradigm* (Frings, Rothermund, & Wentura, 2007). In this paradigm, participants typically perform a choice reaction time task in which targets (e.g., letter stimuli) call for one of two responses (e.g., left vs. right keypress) while targets are accompanied by distractor stimuli (e.g., flanker stimuli to the left and

right of the target). Crucially, these experiments aim at studying sequential dependencies for two successive responses, either by explicitly implementing a prime-probe sequence or by analyzing sequential effects for a continuous series of responses (Moeller, Frings, & Pfister, 2016). Irrespective of the precise design used, we refer to the currently analyzed trial as *probe* and its immediately preceding trial as *prime* trial in the following argument.

Sequential analyses of such designs allow for measuring distractor-response binding by modeling performance (response times and error

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percentages) as a joint function of the response sequence (repetition vs. alternation) and the distractor sequence (repetition vs. alternation) from prime to probe. Distractor repetitions typically improve performance for response repetitions whereas distractor repetitions impair performance of response alternations (relative to distractor alternations). This pattern of results is taken as evidence that features of the distractor and the response become integrated in an event file during the prime, which is retrieved in the probe if one of the features is reactivated, for example, by repeating the distractor stimulus from prime to probe (Hommel, 1998; Rothermund, Wentura, & De Houwer, 2005). In technical terms, distractor-response binding thus becomes evident as an interaction of the response sequence factor and the distractor sequence factor, and the presence and strength of this interaction can be used to study relevant preconditions and moderators of event-file binding and retrieval.

In addition to distractor and response features, event files further incorporate additional features relating to the target stimulus and possible effects of the response (Bogon, Thomaschke, & Dreisbach, 2017; Colzato, van Wouwe, & Hommel, 2007; Dutzi & Hommel, 2009; Giesen & Rothermund, 2011; Hommel, 2005; Huffman, Hilchey, & Pratt, in press; Janczyk, Heinemann, & Pfister, 2012; Moeller, Pfister, Kunde, & Frings, 2016; Schwarz, Burger, Dignath, Kunde, & Pfister, 2018). Crucially, however, bindings are often assumed to be binary, that is, event files are conceptualized as a set of bindings between feature pairs which are independent of bindings between other features in the event file. Therefore, it is reasonable to consider pairwise bindings individually, and we focus on distractor-response bindings in the following.

The literature on distractor-response binding describes a wide range of preconditions and moderators of binding and retrieval, such as perceptual grouping (Frings & Rothermund, 2011; Moeller, Rothermund, & Frings, 2012), attentional allocation (Hommel, Memelink, Zmigrod, & Colzato, 2014; Moeller & Frings, 2014a), or temporal decay (Frings, 2011; Moeller, Pfister et al., 2016). One particular moderator for binding and retrieval which has been proposed in previous work is the *congruency* of distractor and target stimulus (Frings et al., 2007; Moeller & Frings, 2014b). This situation is especially relevant when distractors and targets come from the same item pool so that the relevant mapping rule can be applied not only to the target but also to the distractor stimuli (e.g., Davelaar, 2013; Frings, 2011; Wiswede, Rothermund, & Frings, 2013). Here, the interesting question is whether the integration of distractor and responses during the prime is impaired if distractor- and target-associated responses are in conflict, that is, for incongruent prime trials as compared to congruent prime trials.<sup>1</sup>

## DOES TARGET-DISTRACTOR CONGRUENCY MODERATE DISTRACTOR-RESPONSE BINDING?

A tempting approach to answer this question is to compute distractor response binding separately for congruent and incongruent prime trials so that the three-way interaction of prime congruency, response

sequence, and distractor sequence informs about differences in distractor-response binding depending on congruency during the integration of distractor and response. At first sight, this approach yielded clear-cut results by showing strong and robust distractor-response binding for congruent prime trials but reduced and numerically even reversed binding for incongruent prime trials (Moeller & Frings, 2014b).

On closer inspection, however, this methodology confounds the assumed moderating role of prime congruency (i.e., the three-way interaction of prime congruency, response sequence, and distractor sequence) with target-distractor congruency in the probe trial. To illustrate this point, we will assume the same design as used by Moeller and Frings (2014b), in which target letters were flanked by triplets of arrowheads which pointed either to the left or to the right (e.g., “<<< F >>>”). Figure 1 breaks down the individual trial sequences according to the differential contribution of congruent and incongruent probe trials. Following this argument, the three-way interaction of prime congruency, response sequence, and distractor sequence actually is (at least partially) a disguised measure of probe congruency.

The fundamental problem in comparing distractor-response binding effects for congruent and incongruent primes (or probes, for that matter) is that in typical experimental setups, each stimulus is compatible to a single response. Consequently, alternating the distractor category entails alternation of the associated response, meaning that distractor sequence, response sequence, and congruency in prime and probe are not independent. For example, if the distractor-associated and actually performed response are congruent during the prime, probe distractor and response are always congruent if both response and distractor are repeated or both are alternated, but they are incongruent if either distractor or response are alternated while the other repeats. Of course, the same logic holds for distractor/response-incongruent primes.<sup>2</sup> For the sketched experimental design, it is therefore impossible to differentiate any effect of congruency on distractor- and response integration in the prime, from a mere effect of distractor-response congruency during the probe. Both predict a less pronounced data pattern that is typical for distractor-response binding for incongruent than for congruent primes.<sup>3</sup>

To demonstrate the impact of this confound, we simulated data for 20 fictitious studies (the simulation code and the results that were used for all following analyses are available on the Open Science Framework, [osf.io/d3gk2/](https://osf.io/d3gk2/)).<sup>4</sup> These studies were set to have 42 participants each, with 200 trials for each participant. Targets and distractors were sampled randomly with replacement for a vector of 200 consecutive trials. These trials were then coded as congruent if target and distractors were associated to the same response whereas trials were coded as incongruent if target and distractors were associated to opposite responses.

To generate the data, we used a simple model that only drew on the individual mean response time,  $\overline{RT}$ , a hypothetical congruency effect in the probe trial, and a random error term.  $\overline{RT}$  was sampled from a normal distribution with a mean of 500 ms and a SD of 100 ms:  $\overline{RT} \sim N(500, 100)$ . It was constant for each participant and RTs for individual trials of this participant were sampled from a normal distribution with this mean and a standard deviation of 100 ms. We

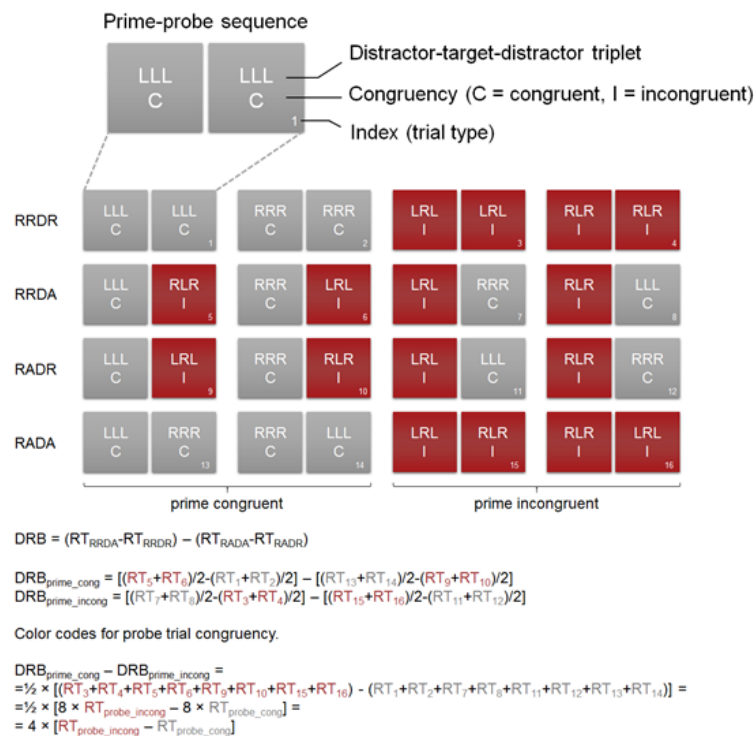


FIGURE 1.

Sketch of possible prime-probe sequences of a distractor-response binding paradigm in which a central target letter is flanked by two distractors to the left and right. Target and distractors can be associated either with a left response (L) or a right response (R); the displayed letter triplets thus represent the associated response of both target (center) and distractors (flankers) and the figure assumes a compact experimental design with only one distractor for left and right responses, respectively (following the design of Moeller & Frings, 2014b). Each prime-probe sequence is classified as one of four conditions: response repetition and distractor repetition (RRDR), response repetition and distractor alternation (RRDA), response alternation and distractor repetition (RADR), or response alternation and distractor alternation (RADA). Mean RTs and error percentages in these conditions can be used to calculate distractor-response binding effects (DRB) as detailed in the formulas for mean RT (the last two formulas require an equal number of trials per trial type to yield exact results). Color coding of the individual trial types codes the congruency of the corresponding probe trials with incongruent probe trials being printed in dark red and congruent probe trials being printed in light grey.

then determined randomly for each trial whether it was congruent or incongruent ( $p_{\text{congruent}} = p_{\text{incongruent}} = 0.5$ ), and computed the current response time  $RT_i$  (with  $1 \leq i \leq 200$ ) as

$$RT_i = \begin{cases} N(\overline{RT}, 100) & \text{for congruent probe trials} \\ N(\overline{RT}, 100) + N(20, 200) & \text{for incongruent probe trials} \end{cases}$$

Importantly, this model did not include any effect of distractor-response binding or a modulation thereof by prime trial congruency. To verify that the simulation worked as intended, we analyzed the first simulated study with a repeated-measures analysis of variance (ANOVA) with the factors of probe congruency (congruent vs. incongruent), response sequence (repetition vs. alternation), and distractor sequence (repetition vs. alternation). The results of this analysis indicated that the model worked as intended by producing a pronounced effect of probe congruency and no further main effects or interactions (Table 1, left results). When coding for prime congruency instead of probe congruency, however, the modelled probe congruency effect reappeared as the three-way interaction of prime congruency, response sequence, and distractor sequence, spuriously suggesting a modulation of distractor-response binding by prime congruency (Table 1, right results). Accordingly, each of the 20 simulated studies

yielded a large difference between the distractor-response binding effects computed for congruent and incongruent prime trials (see Figure 2 for the first 10 studies).

The above argument and demonstration suggest that typical binding paradigms are inappropriate to compare binding effects for congruent and incongruent distractor stimuli. Yet, the question whether an existing (congruent or incongruent) association between stimulus and response influences stimulus-response binding, and thus mechanisms of action control, remains an important one. For example, if one is interested in the mutual influence of binding and learning processes (e.g., Colzato, Raffone, & Hommel, 2006; Herwig & Waszak, 2012; Moeller & Frings, 2017a), one might want to compare binding at the beginning and after a process of stimulus-response association.

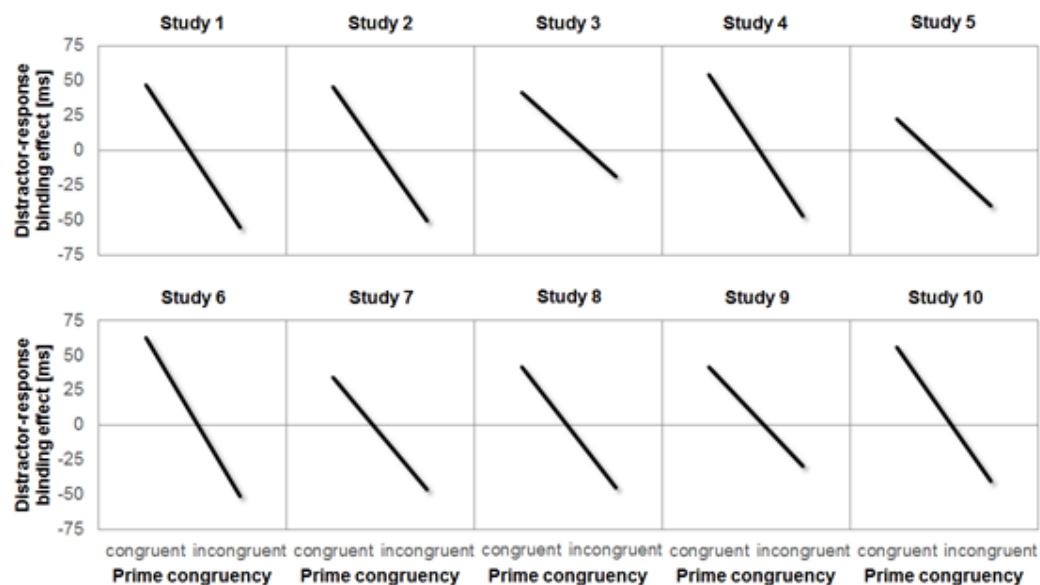
One way to circumvent the described problem and analyze at least part of the influence congruency has on binding in action control, is to focus on exclusively incongruent pairings. Each stimulus is incongruent with multiple responses in the typical binding paradigms, allowing repetition of incongruency independent of distractor- and response sequence (Mordkoff, 2012). Results for incongruent conditions can then be com-

**TABLE 1.**

Validation of the Argument via Simulation Results

Model check: Probe Congruency			Prime congruency		
Source	<i>F</i> (1, 14)	<i>p</i>	Source	<i>F</i> (1, 41)	<i>p</i>
Probe Congruency [ProbeC]	48.11	.001	Prime Congruency [PrimeC]	0.13	.718
Response Sequence [RS]	1.07	.307	Response Sequence [RS]	1.07	.307
Distractor Sequence [DS]	0.11	.740	Distractor Sequence [DS]	0.11	.740
ProbeC × RS	0.28	.598	PrimeC × RS	0.19	.666
ProbeC × DS	0.19	.666	PrimeC × DS	0.28	.598
RS × DS	0.41	.524	RS × DS	0.41	.524
ProbeC × RS × DS	0.13	.718	PrimeC × RS × DS	48.11	.001

*Note.* The simulation only assumed a congruency effect in the probe trial but no modulation of probe response times by the preceding prime trial (i.e., no distractor-response binding). An analysis of variance (ANOVA) with the factors of congruency in the probe trial, response sequence, and distractor sequence yielded a reliable congruency effect and no other significant results. When using prime congruency instead of probe congruency, however, the congruency effect of the probe-trial reappears as the three-way interaction of prime congruency, response sequence, and distractor sequence.

**FIGURE 2.**

Distractor-response binding effects computed separately for congruent and incongruent prime trials for the first 10 studies of the simulated data set (the remaining studies show the same stable pattern). Results conform to the derivation in Figure 1, with the difference between the two distractor-response binding effects being four times as large as the corresponding congruency effect.

pared to a condition with neutral distractors (which allow for an orthogonal manipulation just as well) to gauge the impact of incongruency (for results suggesting no impact of incongruent relative to neutral distractors, see Giesen, Frings & Rothermund, 2012). Alternatively, it is possible to vary the degree of incongruency (i.e., distractors that are arbitrarily mapped to targets' responses in the context of the experiment vs. distractors that are strongly associated with targets' responses on a long-term basis) to assess how much a strong long-term stimulus-response-association can hinder binding of new distractor-response pairings in action control (see Moeller & Frings, 2017b).

## CONCLUSIONS

Following the above argument, we suggest that computing distractor-response binding separately for congruent and incongruent prime (or probe) trials does not inform about a possible moderating role of target-distractor congruency for event-file binding. This is not to say that such a theoretically plausible influence does not exist, but previous results reported in this direction should be treated with caution. A possible solution for this issue is to draw on studies that focus exclusively on incongruent or neutral distractors to assess the effect of incongruence on binding effects.

## ACKNOWLEDGEMENTS

This publication was funded by the German Research Foundation (DFG) and the University of Wuerzburg in the funding programme Open Access Publishing

## FOOTNOTES

<sup>1</sup> It is possible to distinguish three relevant kinds of (in)congruency or (in)compatibility if distractors and targets are drawn from the same item pool. First, there can be a match or mismatch between the response that is associated with the distractor and the correct target-response. Second, there can be a match or mismatch between the distractor stimulus and the target stimulus due to similar or dissimilar perceptual features. Third, if there is dimensional overlap between distractor features and response features, the distractor can be (in)compatible with the target-response (e.g., due to spatial features inherent in the distractor stimulus). Since these aspects often vary together in the typical design, we will more generally refer to (in)congruent primes/probes in the following.

<sup>2</sup> A classical way to circumvent this issue for incongruent trials is to map multiple stimuli to each response (e.g., Bertelson, 1965; Eriksen & Eriksen, 1975). This solution cannot be applied to congruent trials for logical reasons, however: If a congruent prime is repeated and the response is repeated as well, then the probe trial will always be congruent.

<sup>3</sup> Note that comparing distractor-response binding effects for congruent and incongruent probes entails a slightly different issue (especially for the case of tasks with two response options). Congruent probes are always preceded by congruent primes if both response- and distractor-sequences repeat (or alternate), and by incongruent primes if only one of them alternates. By contrast, incongruent probes are preceded by incongruent primes if both response and distractor repeat (or alternate) and by congruent primes if only one of them alternates. Hence, in this case, distractor-response binding effects, as measured in congruent and incongruent probes, are differently influenced by congruency sequence effects (Gratton, Coles, & Donchin, 1992; Hommel, Proctor, & Vu, 2004; Moeller & Frings, 2014b).

<sup>4</sup> The outcome of the simulation necessarily mirrors the formal deduction displayed in Figure 1. We still found it useful and instructive to validate our considerations via simulated results.

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RECEIVED 13.11.2018 | ACCEPTED 22.05.2019